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NAVIER-STOKES ANALYSIS OF COLD SCRAMJET-AFTERBODY FLOWS

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EFFORTS FOR PARABOLIZED NAVIER-STOKES SOLUTIONS

A 3-D space marching parabolized Navier-Stokes code is being developed (modified) to compute the supersonic mixing flow through an internal/external expansion nozzle with multicomponent gases (PMAB3). This flowfield has been computed for a 2-D approximation using a full N-S code (refs. 1, 2). Examination of the 2-D solution results from the full N-S solver reveals several important features of this flow:

(1) The flow is predominantly supersonic and hypersonic

(2) The streamwise velocities are predominantly positive.

Flows with these features lend themselves quite readily to solution by very fast and efficient parabolic Navier-Stokes solvers. A 3-D full N-S solver for multicomponent flow requires an enormous amount of CPU time and memory. Thus, it is not a very likely candiate for preliminary design and analysis of many different nozzle configurations. It is with this in mind that the PNS solver is being developed.

The space marching PNS solver being modified solves the 3-D PNS equations, coupled with a set of species continuity equations, using an implicit finite difference scheme. The species continuity equations are solved with the assumption of a single binary diffusion coefficient. Turbulence closure is obtained by the Baldwin-Lomax eddy viscosity model.

The solutions of the internal flow and the external flow up to the tip of the cowl are being obtained separately (due to the nature of the parabolized equations, the internal flow upstream of the cowl tip is independent of the external flow up to the cowl tip). The solution plane at the cowl tip for both internal and external flow is then being used at an initial plane solution for the outer "mixing" region.

The external flow has been obtained for a "theoretical" air mixture (79% N_2, 21% O_2) by assuming an 18" flat plate with a side wall upstream of the cowl. This flat plate and side wall causes a system of leading edge shocks and 3-D boundary layers to develop prior to reaching the cowl tip.

The solution of the internal nozzle flow has posed a slight problem. The gases in the nozzle model are expanded to supersonic speeds from a high pressure reservoir. By the time the flow has reached the inner throat of the nozzle, a boundary layer on each of the walls has developed. Since no experimental data for the 3-D corner flow profile exists, one must be assumed (as was in the 2-D study of refs. 1, 2). An "inviscid" free stream initial plane can not be used in this region due to the fact that leading edge shocks would develop within the nozzle, thus severely degrading the solution downstream. In an actual design analysis case, the upstream profiles of independent variables would be known apriori (either from experimental data, or from the solution output of the upstream flow by another N-S solver). Since this data does not exist at this time, a "quasi-3D" corner flow profile has been assumed for code development purposes. This "quasi-3D" profile was constructed by stacking 2-D b.l. profiles in the longitudinal and horizontal planes. The thickness of the boundary layer on each of the three walls (the fourth side is treated as a reflection plane of symmetry) is assumed to be 7% of the nozzle throat height. Figure 1 shows a cross flow plane of density contours on the initial profile ($x = 0$) plane.

At the present time, the work completed is as follows:

(1) Code has been modified to solve for 4 chemical species:

$$(N_2, O_2, F_{(12)}, Ar)$$

(2) The flow upstream of the upper cowl surface, up to and including the cowl tip, has been computed for a "theoretical air" mixture (79% N_2, 21% O_2) at $M_\infty = 6$.

(3) A "quasi 3D" corner flow profile has been developed to be used as an initial plane solution for the inner nozzle region.

(4) The flow inside the nozzle, up to and including the cowl tip, has been computed for both the N_2/O_2 mixture and the $F_{(12)}$/Ar mixture at $M_{throat} = 1.665$. Figures 2 and 3 show density and pressure contours for the inner nozzle region (constant z-plane at the reflection boundary).

Work is in prograss to obtain the solution in the mixing region (region downstream of the cowl tip) by using the solutions from the internal and external regions upstream of the cowl tip as initial inflow conditions (Fig. 4).

EFFORTS FOR FULL NAVIER-STOKES SOLUTIONS

This 3-D Navier-Stokes equations solver has the species continuity equations to account for the diffusion of multiple gases. Also, it has the ability to use high order numerical integration schemes such as the 4th order MacCormack, and the Gottlieb-MacCormack schemes. This 3-D explicit afterbody code is referred to as EMAB3 for brevity in this report.

The status of this work may be itemized as follows:

1. EMAB3 Code has been modified, so that this code is now capable of computing internal/external flows.

2. It also allows the existence of a wall inside of computation zone.

3. The Navier-Stokes solver has been modified to implement new boundary conditions on cowl walls.

4. The Navier-Stokes solver has been modified to "relax" computations around the cowl region, especially near the cowl tip, to increase the stability of the computations to get past the initial numerical transients.

5. Further modifications are performed,

   a) to apply appropriate boundary conditions for three solid walls and single free stream boundary

   b) to apply turbulence modeling in the appropriate flow regions consistent with the solid surfaces.

6. The thermodynamic and transport properties of Freon-12, Argon, Oxygen, and Nitrogen have been entered in the code.

7. The current grid (Fig.) has been generated by an algebraic method combined with a 1-D stretching algorithm designed to yield smooth cell distributions through all segments of the grid boundaries.

8. In flow profiles of the primitive variables were generated for both the internal nozzle and external flows using the appropriate gaseous properties, the upstream conditions and the PMAB3 code. The initial conditions of variables downstream of the inflow boundary were set the same as the inflow profiles of the primitive variables.

9. The turbulence model (Baldwin-Lomax) in the Navier-Stokes solver has been modified to account for turbulent eddies generated by cowl walls inside and external to the nozzle. Also, a relaxation formula was adopted to account for the turbulence in the mixing shear layer.

10. The Navier-Stokes solver has been modified such that the differences around the cowl are one-sided (Fig. 6).

REFERENCES

1. Baysal, O., Engelund, W. C., Tatum, K. E., "2-D Navier-Stokes Calculations of Scramjet-Afterbody Flowfields," ASME-FED, Vol. 66, pp. 49-60, November 1988. Also NASP-CR-1035.

2. Baysal, O., Engelund, W. C., Eleshaky, M. E., Pittman, J. L., "Adaptive Computations of Multispecies Mixing Between Scramjet Nozzle Flows and Hypersonic Freestream," AIAA Paper No. 89-0009, January 1989.

region A x=1 plane
(upstream B.L. profile)

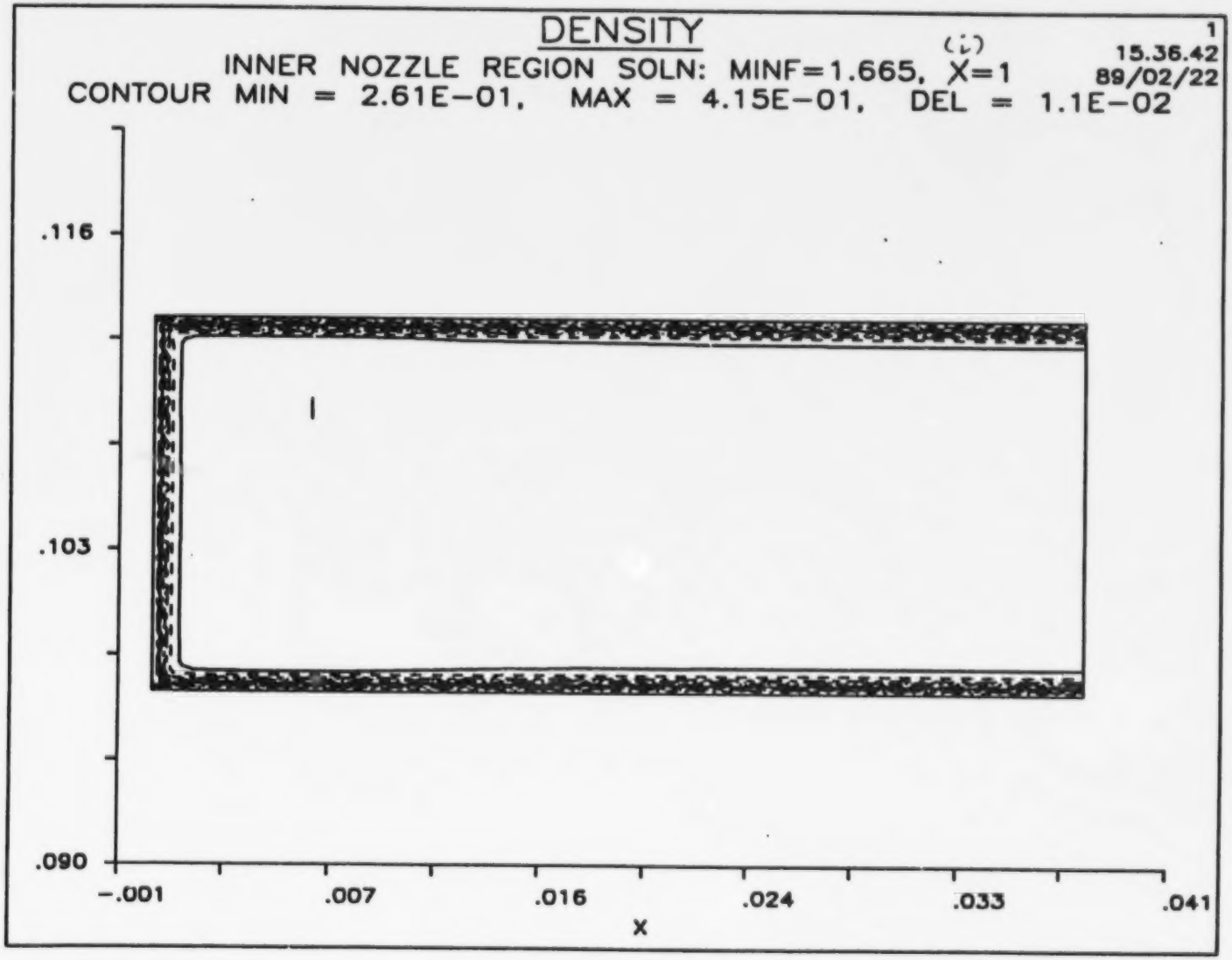


Figure 1.

2-40
(reflection plane)

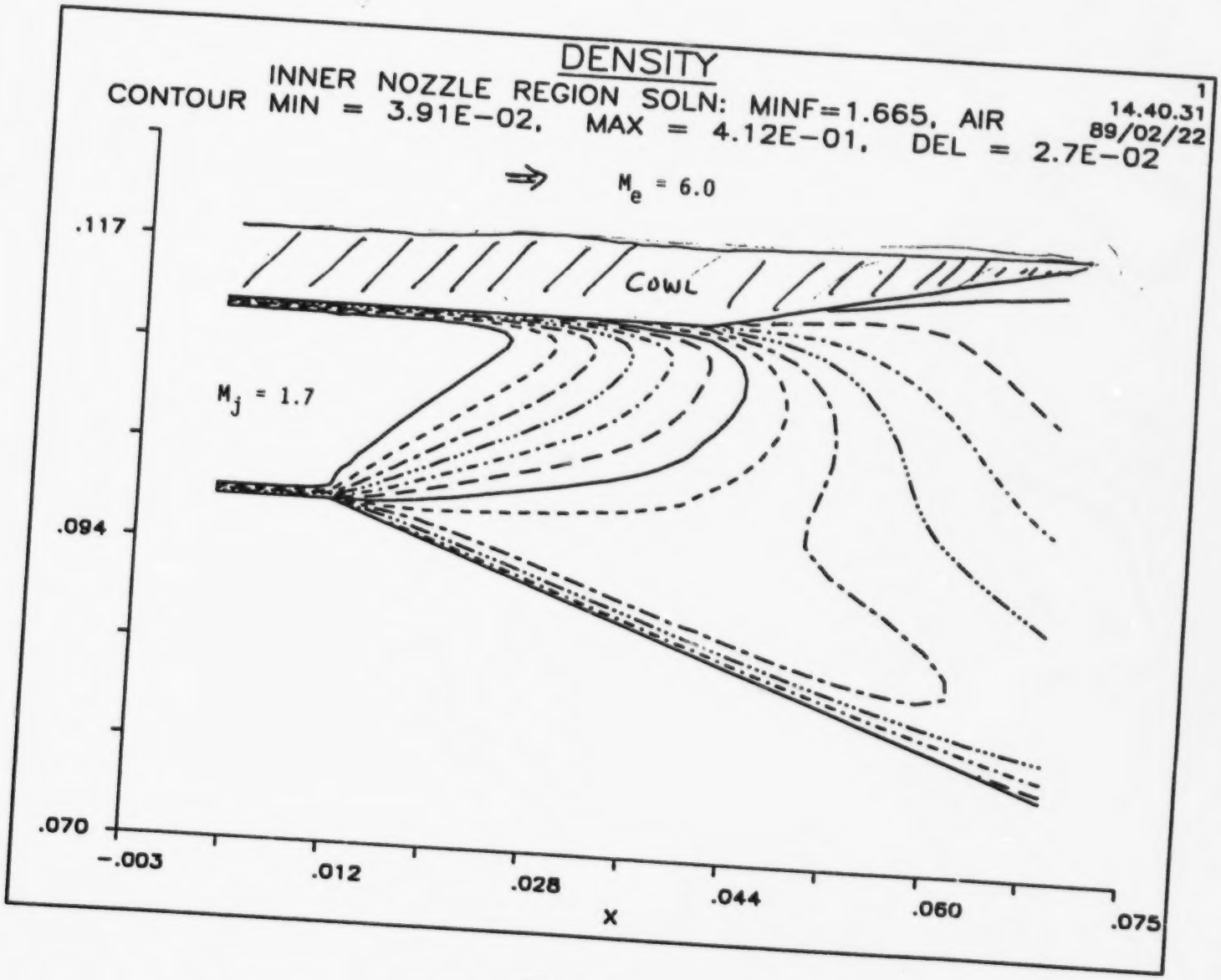


Figure 2.

z = 4c.
(reflection plane)

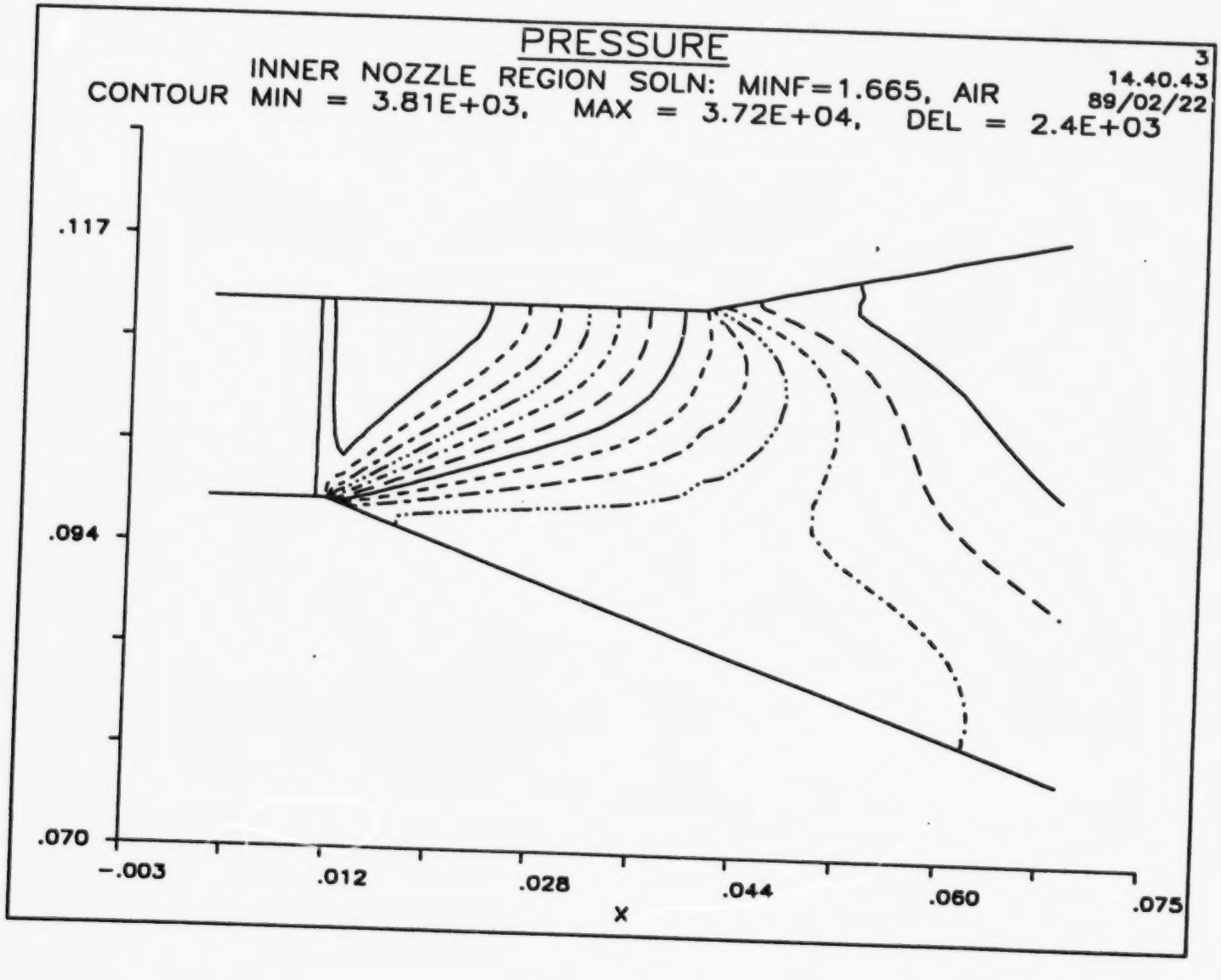
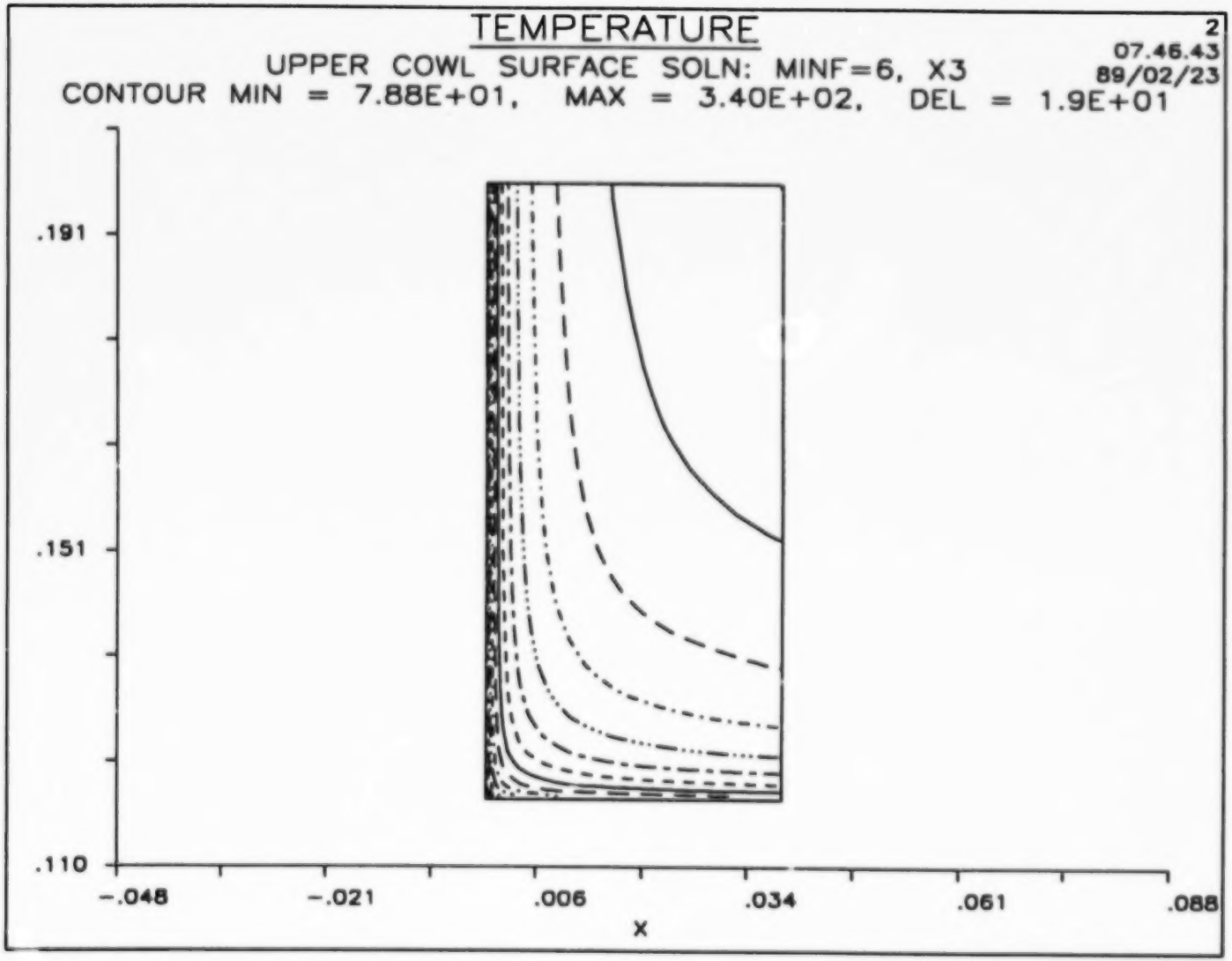


Figure 3.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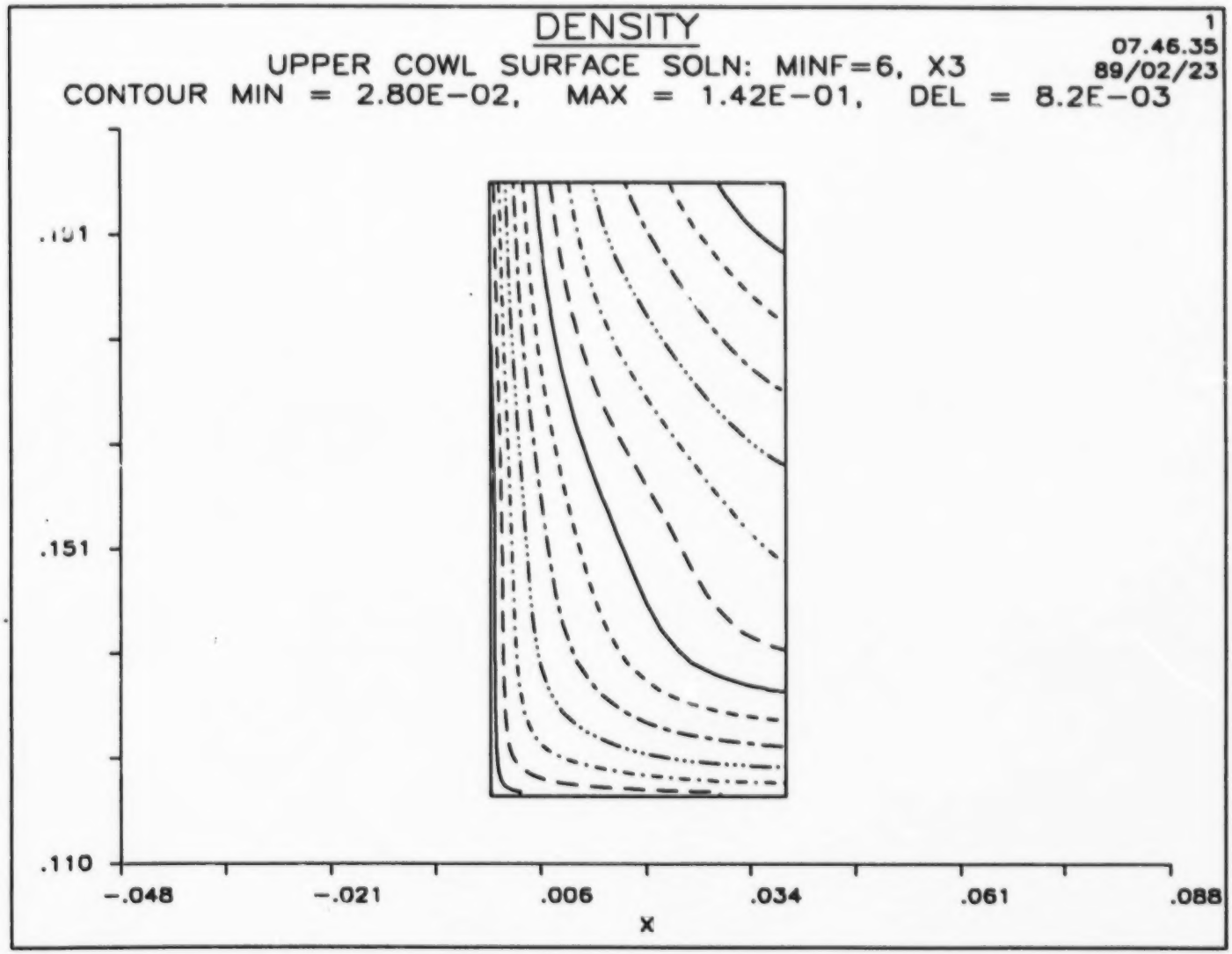
.088
X

Figure 4a.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X

Figure 4b.

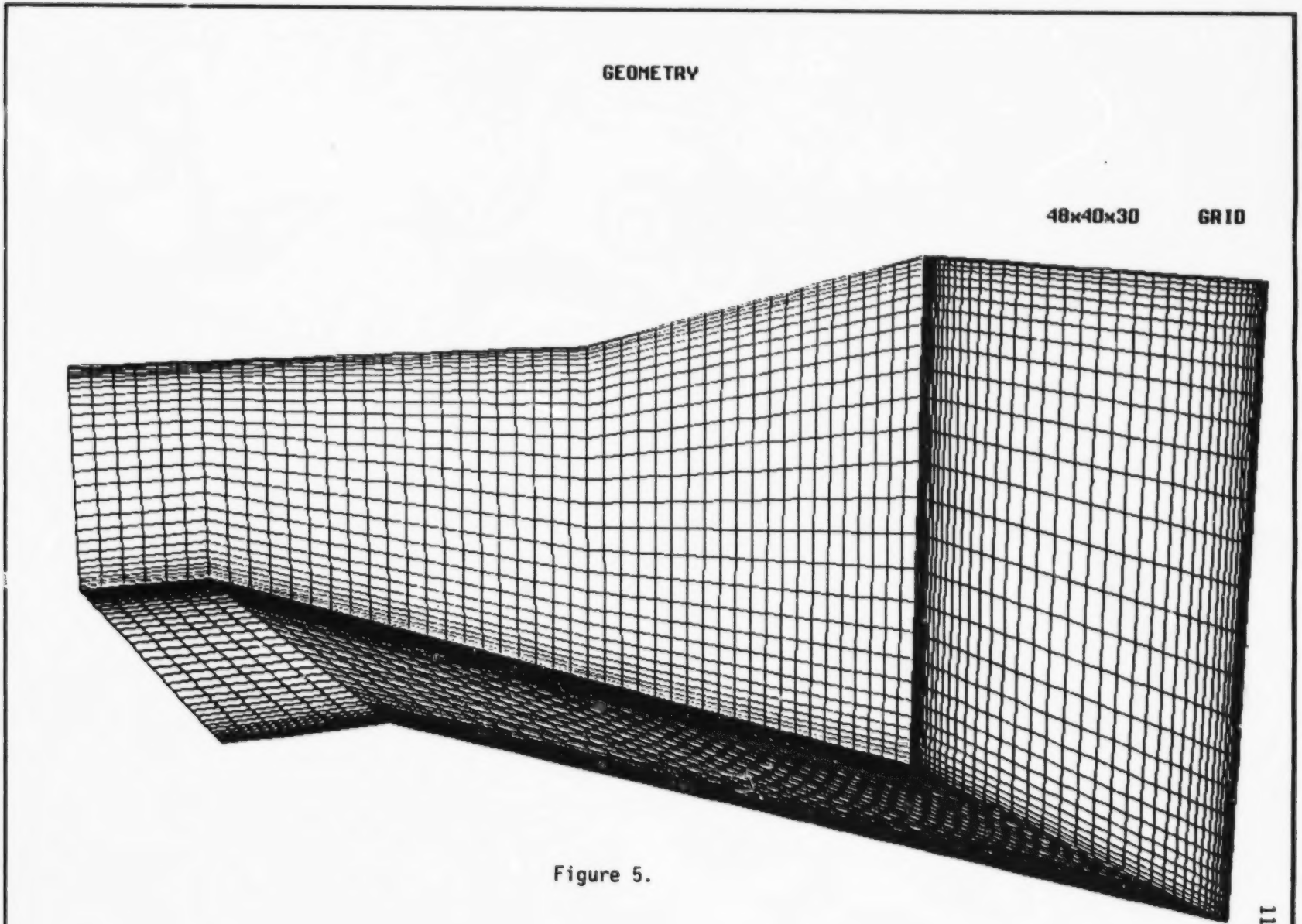

Figure 5.

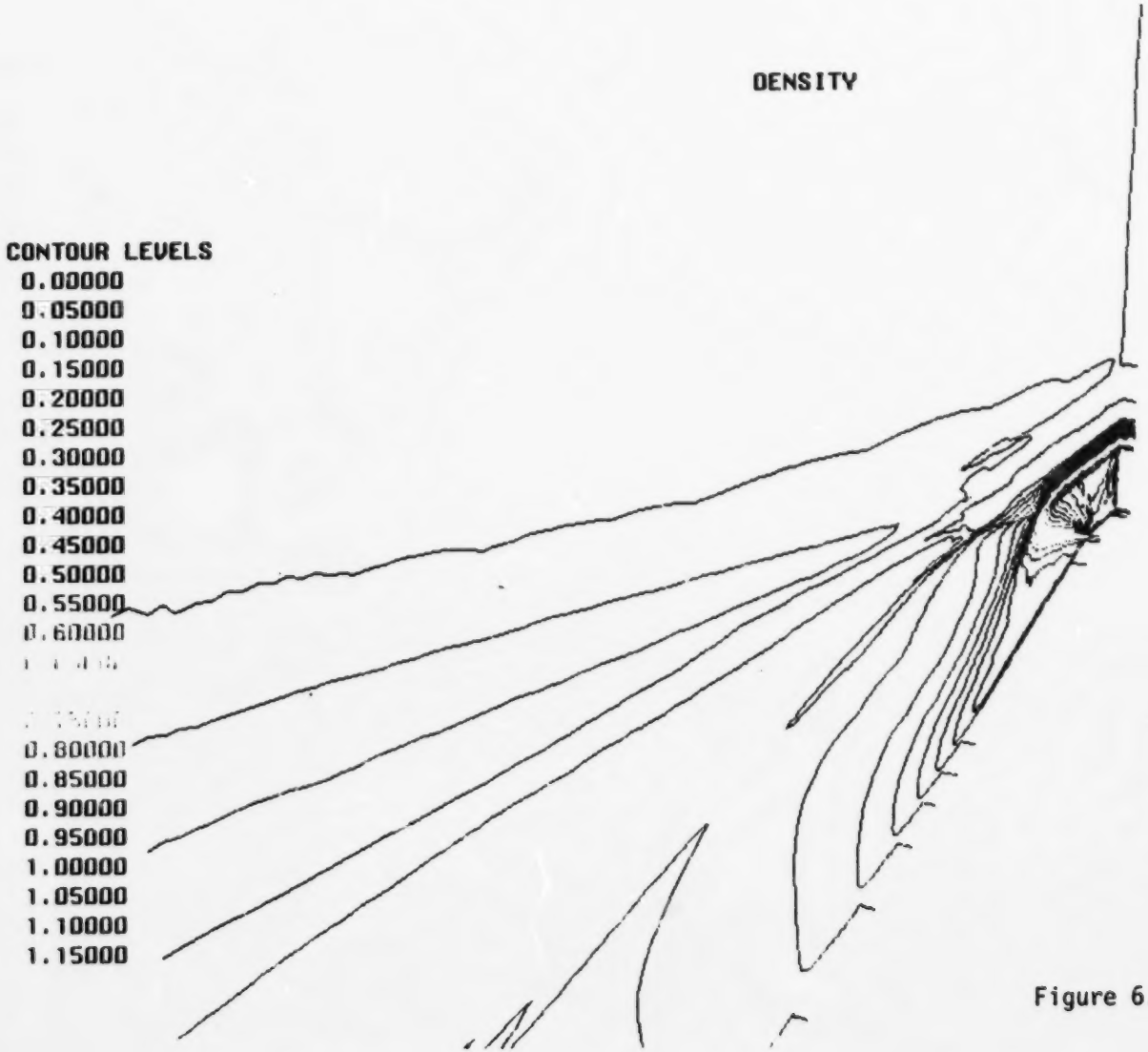

Figure 6.

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